# Einstein: Theory of Relativity

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# Einstein: Theory of Relativity

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**Abstract:**

When Albert Einstein's theory of relativity had published, only 12 person of that era could understand this theory. One day, a young journalist asked Einstein to explain his theory. Then he explained his theory with a joke. He told that, "When a man converse story with a beautiful girl for one hour, it seems to him that it's past only one minute. And if anyone stand on stove for a minute, it seems to him that he is stand here for one hour. This is relativity".

Albert Einstein's theory of relativity is actually two separate theories: his *special theory of relativity*, postulated in the 1905 paper, *The Electrodynamics of Moving Bodies* and his *theory of general relativity*, an expansion of the earlier theory, published as *The Foundation of the General Theory of Relativity* in 1916. Einstein sought to explain situations in which Newtonian physics might fail to deal successfully with phenomena, and in so doing proposed revolutionary changes in human concepts of time, space and gravity. The special theory of relativity was based on two main postulates: first, that the speed of light is constant for all observers; and second, that observers moving at constant speeds should be subject to the same physical laws.

**Keywords:** *Speed, Times, Gravity, Theory of Relativity, Motion, Relativity*

**Introduction:**

Until the end of the 19th century it was believed that Newton's three Laws of Motion and the associated ideas about the properties of space and time provided a basis on which the motion of matter could be completely understood. However, the formulation by Maxwell of a unified theory of electromagnetism disrupted this comfortable state of affairs – the theory was extraordinarily successful, yet at a fundamental level it seemed to be inconsistent with certain aspects of the Newtonian ideas of space and time. Ultimately, a radical modification of these latter concepts, and consequently of Newton's equations themselves, was found to be necessary.

It was Albert Einstein who, by combining the experimental results and physical arguments of others with his own unique insights, first formulated the new principles in terms of which space, time, matter and energy were to be understood. These principles, and their consequences constitute the Special Theory of Relativity. Later, Einstein was able to further develop this theory, leading to what is known as the General Theory of Relativity. Amongst other things, this latter theory is essentially a theory of gravitation. The General Theory will not be dealt with in this course.

Relativity (both the Special and General) theories, quantum mechanics, and thermodynamics are the three major theories on which modern physics is based. What is unique about these three theories, as distinct from say the theory of electromagnetism, is their generality. Embodied in these theories are general principles which all more specialized or more specific theories are required to satisfy. Consequently these theories lead to general conclusions which apply to all physical systems, and hence are of enormous power, as well as of fundamental significance. The role of relativity appears to be that of specifying the properties of space and time, the arena in which all physical processes take place. It is perhaps a little unfortunate that the word 'relativity' immediately conjures up thoughts about the work of Einstein. The idea that a principle of relativity applies to the properties of the physical world is very old: it certainly predates Newton and Galileo, but probably not as far back as Aristotle. What the principle of relativity essentially states is the following:

*The laws of physics take the same form in all frames of reference moving with constant velocity with respect to one another.* [1]

The theory of relativity is intimately connected with the theory of space and time. The only justification for our concepts and system of concepts is that they serve to represent the complex of our experiences; beyond this they have no legitimacy, We can form new bodies by bringing bodies B,C,….. up to A; we say that we continue body A. We can continue body A such a way that it comes into contact with any other body, X. The ensemble of all continuations of body A, we can designate as the "Space of the body A." Then it is true that all bodies are in the "Space of the (arbitrarily chosen) body A." In this sense we cannot speak of space in the abstract, but only of the "Space belonging to a body A." The earth crust's play's such a dominate role in our daily life in judging the relative positions of bodies that it has led to an abstract conception of space which certainly cannot be defended. In order to free ourselves from this fetal error we shall speak only through the theory of general relativity that refinement of these concepts became necessary, as we shall see later. It is assumed in pre-ralativity physics that the laws of the orientation of ideal rigid bodies are consistent with Euclidean geometry. What this mean may be expressed as follow: Two points marked on a rigid body form an interval. Such an interval can be oriented at rest, relatively to our space of reference, in a multiplicity of ways. If, now, the points of this space can be referred to co-ordinates $x_1, x_2, x_3$, in such a way that the differences of the co-ordinates, $\Delta x_1, \Delta x_2, \Delta x_3$, of the two ends of the interval furnish the same of squares,

$$s^2 = \Delta x^{12} + \Delta x^{22} + \Delta x^{32}$$

for every orientation of the interval, then the space of reference is called Euclidean, and the co-ordinates Cartesian.* [2]

* This relation must hold for an arbitrary choice of the origin and of the direction (ratios $\Delta x_1 : \Delta x_2 : \Delta x_3$) of the interval.

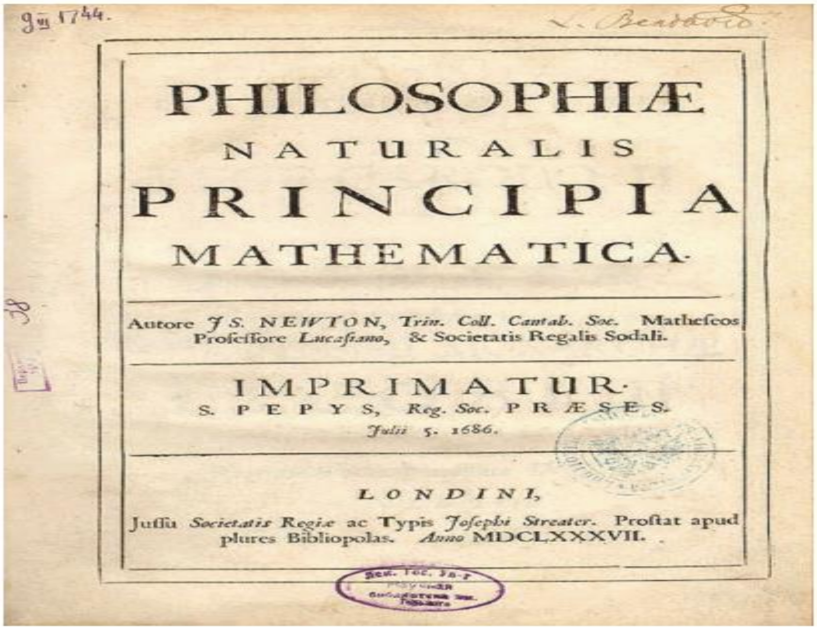
The importance of the Theory of Relativity for twentieth-century physics, and the appearance of the Gottingen mathematician Hermann Minkowski at a turning point in its history have both attracted significant historical attention The rapid growth in scientific and philosophical interest in the principle of relativity has been linked to the intervention of Minkowski by Tetu Hirosige. [3]

Why did special relativity emerge when it did? The answer is already given in Einstein's 1905 paper. It is the fruit of 19th century electrodynamics. It is as much the theory that perfects 19th century electrodynamics as it is the first theory of modern physics. 4 Until this electrodynamics emerged, special relativity could not arise; once it had emerged, special relativity could not be stopped. Its basic equations and notions were already emerging in the writings of H. A. Lorentz and Henri Poincaré on electrodynamics. The reason is not hard to understand. The observational consequences of special relativity differ significantly from Newtonian theory only in the realm of speeds close to that of light. Newton's theory was adapted to the fall of apples and the slow orbits of planets. It knew nothing of the realm of high speeds. Nineteenth century electrodynamics was also a theory of light and the first to probe extremely fast motions. The unexpected differences between processes at high speeds and those at ordinary speeds were fully captured by the electrodynamics. But their simple form was obscured by elaborate electrodynamical ornamentations. Einstein's achievement was to strip them of these ornamentations and to see that the odd behavior of rapidly moving electrodynamical systems was not a peculiarity of electricity and magnetism, but imposed by the nature of space and time on all rapidly moving systems. This chapter will present a simple statement of the essential content of Einstein's special theory of relativity, including the inertia of energy, $E = mc^2$ . It will seek to explain how Einstein extracted the theory from electrodynamics, indicating the subsidiary roles played by both experiment and Einstein's conceptual analysis of simultaneity. [4]

**Description:**

**Frames of Reference:**

Newton's laws are, of course, the laws which determine how matter moves through space as a function of time. So, in order to give these laws a precise meaning we have to specify how we measure the position of some material object, a particle say, and the time at which it is at that position. We do this by introducing the notion of a frame of reference.



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore JS. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

**Inertial Frames of Reference and Newton's First Law of Motion:**

In other words we can adopt as a law of nature, the following statement:

*"There exist frames of reference relative to which a particle acted on by no forces moves in a straight line at constant speed."*

This essentially a claim that we are making about the properties of space time. It is also simply a statement of Newton's First Law of Motion. A frame of reference which has this property is called an inertial frame of reference, or just an inertial frame. Gravity is a peculiar force in that if a reference frame is freely falling under the effects of gravity, then any particle also freely falling will be observed to be moving in a straight line at constant speed relative to this freely falling frame. Thus freely falling frames constitute inertial frames of reference, at least locally. [5]

The above argument does not tell us whether there is one or many inertial frames of reference, nor, if there is more than one, does it tell us how we are to relate the coordinates of an event as observed from the point-of-view of one inertial reference frame to the coordinates of the same event as observed in some other.

The transformation equations that we derive are then the mathematical basis on which it can be shown that Newton's Laws are consistent with the principle of relativity. To derive these transformation equations, consider an inertial frame of reference S and a second reference frame S0 moving with a velocity $V_x$ relative to S.

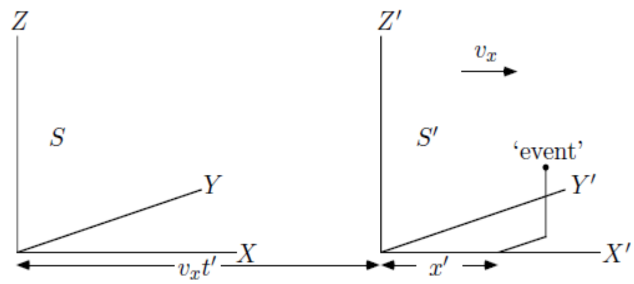



Figure 1: A frame of reference S0 is moving with a velocity $V_x$ relative to the inertial frame S. An event occurs with spatial coordinates (x, y, z) at time t in S and at (x0,y0,z0) at time t0 in S0.

**Newtonian Force and Momentum:**

Having proposed the existence of a special class of reference frames, the inertial frames of reference, and the Galilean transformation that relates the coordinates of events in such frames, we can now proceed further and study whether or not Newton's remaining laws of motion are indeed consistent with the principle of relativity. First we need a statement of these two further laws of motion.

**Newton's Second Law of Motion:**

It is clearly the case that particles do not always move in straight lines at constant speeds relative to an inertial frame. In other words, a particle can undergo acceleration. This deviation from uniform motion by the particle is attributed to the action of a force. If the particle is measured in the inertial frame to undergo an acceleration a, then this acceleration is a consequence of the action of a force F where

$$F = ma$$

and where the mass m is a constant characteristic of the particle and is assumed, in Newtonian dynamics, to be the same in all inertial frames of reference. This is, of course, a statement of Newton's Second Law. This equation relates the force, mass and acceleration of a body as measured relative to a particular inertial frame of reference.

**Newton's Third Law of Motion:**

Newton's Third Law, namely that to every action there is an equal and opposite reaction, can also be shown to take the same form in all inertial reference frames. This is not done directly as the statement of the Law just given is not the most useful way that it can be presented. A more useful (and in fact far deeper result) follows if we combine the Second and Third Laws, leading to the law of conservation of momentum which is

*In the absence of any external forces, the total momentum of a system is constant.* [6]

**The Special Theory of Relativity:**

**A geometrical theory of space time:**

*"I always get a slight brain-shiver, now [that] space and time appear conglomerated together in a gray, miserable chaos." – Sommerfeld*

In 1971, J.C. Hafele and R.E. Keating3 of the U.S. Naval Observatory brought atomic clocks aboard commercial airliners and went around the world, once from east to west and once from west to east. (The clocks had their own tickets, and occupied their own seats.) As in the parable of Alice and Betty, Hafele and Keating observed that there was a discrepancy between the times measured by the traveling clocks and the times measured by similar clocks that stayed at the lab in Washington. The result was that the east-going clock lost an amount of time $\Delta tE = -59 \pm 10$ ns, while the west-going one gained $\Delta tW = +273 \pm 7$ ns. This establishes that time is not universal and absolute. [7]

In each case, a statement about geometric structure (on the left) is correlated with a statement about the behavior of particles or light rays (on the right). Several comments and qualifications are called for. First, we are here working within the framework of relativity as traditionally understood and ignoring speculations about the possibility of particles that travel faster than light. (The worldlines of these so-called "tachyons" would come out as images of spacelike curves.) Second, we have restricted attention to smooth curves. So, depending on how one models collisions of point particles, one might want to restrict attention here, in parallel, to particles that do not experience collisions. Third, the assertions require qualification because the status of "point particles" in relativity theory is a delicate matter. At issue is whether one treats a particle's own mass-energy as a source for the surrounding metric field gab—in addition to other sources that may happen to be present. (Here we anticipate our discussion of Einstein's equation.) If one does, then the curvature associated with gab may blow up as one approaches the particle's worldline. And in this case one cannot represent the worldline as the image of a curve in M, at least not without giving up the requirement that gab be a smooth field on M. For this reason, a more careful formulation of the principles would restrict attention to "test particles"—i.e., ones whose own mass-energy is negligible and may be ignored for the purposes at hand. Fourth, the modal character of the assertions (i.e., the reference to possibility) is essential. It is simply not true—take the case of (C1)—that all images of smooth, timelike curves are, in fact, the worldlines of massive particles. The claim is that, as least so far as the laws of relativity theory are concerned, they could be. Of course, judgments concerning what could be the case depend on what conditions are held fixed in the background. The claim that a particular curve image could be the worldline of a massive point particle must be understood to mean that it could so long as there are, for example, no barriersin the way. Similarly, in (C2) there is an implicit qualification. We are considering what trajectories are available to light rays when no intervening material media are present—i.e., when we are dealing with light rays in vacuo. [8]

**The concept of space in General Relativity:**

- ❖ Special relativity established a new practical geometry allowing to assess the spatio-temporal aspects of physical theories.
- ❖ The anisotropies of space-time such as gravitation could beinterpreted either as fields or as indications of a further modification of space.

- ❖ Problems with the field approach and the universality of gravitation including matter and radiation suggested the latter.
- ❖ In hindsight, the problem was to reconcile a metric with an affine structure of space-time.
- ❖ Its relation to acceleration (Equivalence Principle) suggested a generalization of the relativity principle, conceiving both gravitation and inertia as an effect of masses (Mach's Principle). [9]

**Space Time Four Vectors:**

What we do now is make use of the above considerations to introduce the idea of a vector to describe the separation of two events occurring in spacetime. The essential idea is to show that the coordinates of an event have transformation properties analogous for ordinary three-vectors, though with some surprising differences. To begin, we will consider two events $E_1$ and $E_2$ occurring in spacetime. For event $E_1$ with coordinates ($x_1, y_1, z_1, t_1$) in frame of reference S and ($x_1', y_1', z_1', t_1'$) in $S'$, these coordinates are related by the Lorentz transformation which we will write as

$$\begin{aligned} ct_1' &= \gamma ct_1 - \frac{\gamma v_x}{c} x_1 \\ x_1' &= -\frac{\gamma v_x}{c} ct_1 + \gamma x_1 \\ y_1' &= y_1 \\ z_1' &= z_1 \end{aligned}$$

and similarly for event $E_2$. Then we can write

$$\begin{aligned} c\Delta t' &= c(t_2' - t_1') &&= \gamma c\Delta t - \frac{\gamma v_x}{c} \Delta x \\ \Delta x' &= x_2' - x_1' &&= -\frac{\gamma v_x}{c} c\Delta t + \gamma \Delta x \\ \Delta y' &= \Delta y \\ \Delta z' &= \Delta z \end{aligned}$$

which we can write as

$$\begin{pmatrix} c\Delta t' \\ \Delta x' \\ \Delta y' \\ \Delta z' \end{pmatrix}_{S'} = \begin{pmatrix} \gamma & -\gamma v_x/c & 0 & 0 \\ -\gamma v_x/c & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} c\Delta t \\ \Delta x \\ \Delta y \\ \Delta z \end{pmatrix}_{S} .$$

**Einstein's Two Postulates (1905):**

- **Postulate I (Principle of Relativity):**

  "All laws of physics must be the same ("invariant") in all inertial reference frames". (Cannot detect absolute uniform motion)

- **Postulate II (Constancy of c):**

  "The speed of light in vacuum is constant (same value, $3.00 * 10^{8} ms^{-1}$) in all inertial reference frames, regardless of motion of source or observer"

The special theory of relativity was based on two main postulates: first that the "Speed of Light" is constant for all observers; and second, that "Observers moving at constant speeds should be subject to the same physical law". Following this logic, Einstein theorized that time must change according to the speed of a moving object relative to the frame of reference of an observer. [10]

A final effort was made in order to understand in a "fundamental" way the negative result of the Michelson-Morley experiment. It was postulated (independently) by Fitz-Gerald and by Lorentz that matter moving through the ether is compressed, the degree of compression being just so that there is a negative result in the M&M experiment. The claim was that the ether wind does slow down and speed up light, but it also contracts all objects and these two effects conspire to give no effect in all experiments. A calculation shows that an object of length ` moving with velocity v with respect to the ether should be contracted to length `0 given by

$$\ell' = \ell \sqrt{1 - \frac{v^2}{c^2}}$$

(Where c is the speed of light) in order to get the null result required. [11]

**Newtonian Relativity (Some History):**

- Galilean Transformation of space-time

  –Two observers (1,2) are in their own, separate, inertial frame of reference $S_1$ and $S_2$

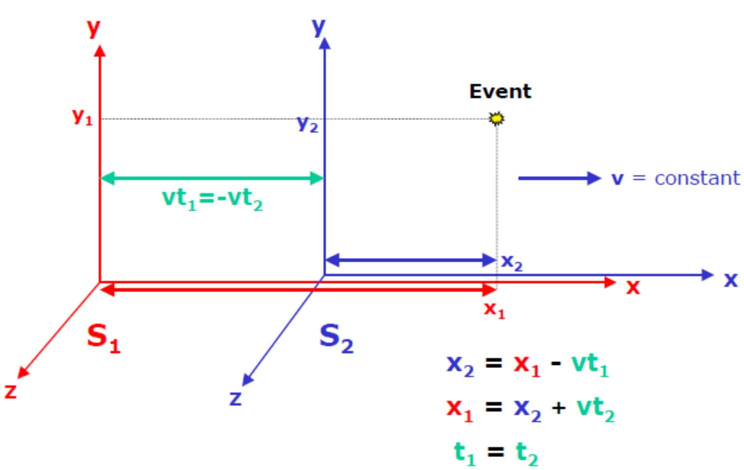
- $S_2$ moves with respect to $S_1$ with v =constant along x-axis

  –Each observes the same "event" giving position and time as measured in their own frame of reference ( $x_1, y_1, z_1, t_1; x_2, y_2, z_2, t_2$ )

- Each has own meter stick and clock
- When temporarily at rest, sticks same length, clocks synchronized i.e. at the instant $t_1 = 0$, then $t_2 = 0$ and x in $S_1$= x in $S_2$
- When $S_2$ is moving with respect to $S_1$, the state (x and t) of the event as seen by the two observers is related by:

$$\begin{aligned} x_2 &= x_1 - vt_1 \\ y_2 &= y_1 \\ z_2 &= z_1 \\ t_2 &= t_1 \end{aligned} \qquad \text{v}\rightarrow \text{-v gives} \quad (S_1 \rightarrow S_2) \qquad \begin{aligned} x_1 &= x_2 + vt_2 \\ y_1 &= y_2 \\ z_1 &= z_2 \\ t_1 &= t_2 \end{aligned}$$

The $S_1$ and $S_2$ Inertial Frames:




[12]

**Failure of Newtonian Relativity:**

- Maxwell's (4) equations describe electromagnetism successfully
- Maxwell's equations predict the existence of e.m. waves propagating through free space with speed $3.00*10^{8} ms^{-1}$

– Question #1: With respect to what frame is c to be measured?

– Question #2: Through what medium do e.m. waves propagate?

– 19th century answer: "Ether" hypothesis - existence of a massless but elastic substance permeating all space

• Electromagnetic waves propagate through the ether

• c is to be measured with respect to the ether

– An experiment is needed to test the presence of ether!

- **Michelson-Morley Experiment (1881):**

– Premise: If one believes in the ether (and that c is $3.00*10^{8} ms^{-1}$ w.r. to it), and in Maxwell's Eqns, and in Galilean transformations for E&M, then if one measures the speed of light in a frame moving w.r. to ether, one should be able to measure v of this moving frame.

– Plan: Measure earth's speed as it moves through ether

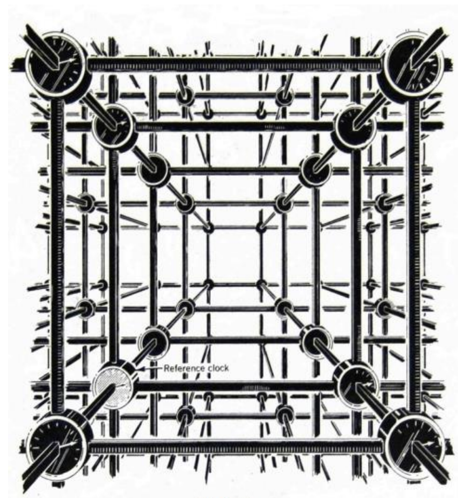
– Result: Null; can not detect any motion of the earth through ether

**Time is what one reads from a local clock:**

First we want to convince ourselves that it is possible to synchronize several identical clocks which are at rest in an inertial frame at different places. Often the following method is suggested: two clocks are at points A and B respectively. A flash of light is released at the midpoint of AB and on arrival of the light each clock is set to 0000 and started. It is however quite possible to synchronize as many clocks as desired with a given clock A: The

!master" clock A emits a flash of light at an arbitrary but well-known time t0. As soon as the light arrives at clock B, it is firstly reflected, secondly B"s clock is set to 0000 and thirdly it is started. Clock A records time t1, when the light reflected from B arrives again at A. One calculates the elapsed time $\frac{t_1 - t_0}{2}$ for the light from A to B, records the value $t_0 + \frac{t_1 - t_0}{2}$ and sends it by snail mail to B. The (continuously running) clock B is then advanced by this value. One does not need the midpoint AB at all and in addition one obtains the distance between the two clocks. [13]


Clock: A




Clock: B

Hans Reichenbach pointed out in different publications starting from 1920 that this definition implies a further assumption, i.e. the isotropy of space (a collection of Reichenbach's early writings on space, time and motion in English translation has been edited by Steven Gimbel and Anke Walz in. [14]

In particular the speed of light should be equal in all directions. Measuring the one-way speed

of light presupposes distant clocks which have already been synchronized. Therefore the synchronization of distant clocks and the measuring of the one-way speed of light have a circular relationship to each other. When we computed the elapsed time for the light from A to B as $\frac{t_1 - t_0}{2}$ we tacitly assumed that the light needs equal time to travel in both directions! The postulate of isotropy was hidden in this assumption. The book “Concepts of Simultaneity” by Max Jammer presents two simple axioms which a set of clocks must meet, in order to be synchronizeable. The formulation of the first axiom is ours:

1. If a clock A sends out two light signals with $\Delta t_A$ time difference, then each further clock B must receive the signals with $\Delta t_B$ time difference, where $\Delta t_B = \Delta t_A$.

2. The time required for light to traverse a triangle is independent of the direction taken around the triangle. [15]

The first axiom must surely be fulfilled if synchronized clocks are to remain synchronized. Obviously it can be fulfilled only by clocks which are at rest relative to each other! The second axiom (called the “round trip axiom") guarantees that the speed of light is independent of direction. Taken together the two axioms are necessary and sufficient so that a set of clocks can be synchronized.

Einstein's insightful contribution to the development of the STR was to show that this operational approach eliminates all difficulties.

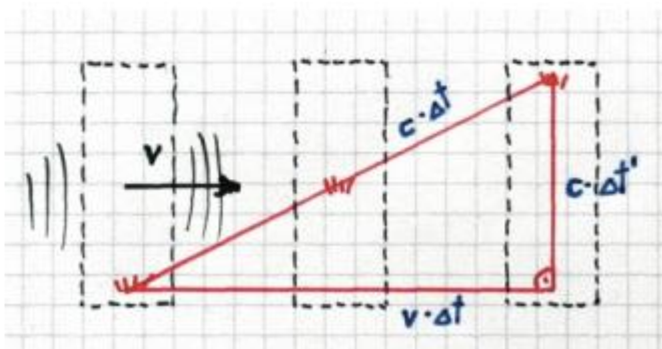
Thus in an inertial frame we can get along with one single time. We are allowed to speak of the time t in an inertial frame. However, different inertial frames usually have different chronologies for events. Epstein demonstrates this very beautifully in [16].

He considers an interstellar fleet of three spaceships, which travel in a row in space at a constant distance from each other:

[17]

**Fast Clocks Tick More Slowly:**

The distance light travels in the moving clock (call it the prime system with measured time $t'$) is 30 cm or, in general, $c.\Delta t'$. But what is the distance this light travels as seen from the resting system (call it the non-prime system with measured time t) and in relation to which the moving clock travels along the x-axis with velocity v? Given the constancy of the speed of light this will be, of course, $c.\Delta t'$. These two distances are however not equal and thus the time intervals, $\Delta t$ and $\Delta t'$, must differ! The Pythagorean Theorem provides us with the relationship between these two values:



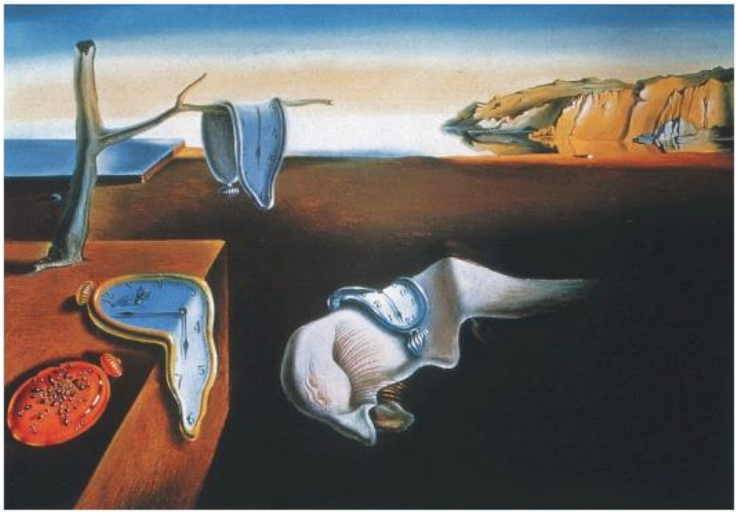

Obviously more time elapsed in the resting, non-prime-system, than in the moving, prime-system, since the light travelled a longer distance in that system. Thus:

$$(c\Delta t)^2 = (v\Delta t)^2 + (c\Delta t')^2$$
$$or, c^2(\Delta t)^2 = v^2(\Delta t)^2 + c^2(\Delta t')^2$$
$$or, (\Delta t')^2 = (\Delta t)^2(1-\frac{v^2}{c^2})$$

and we get

$$\Delta t' = \Delta t\sqrt{1-\frac{v^2}{c^2}} \qquad [18]$$

We have now described the relativity of objective time measurement. That subjective time experience is !malleable" is well-known. Salvador Dali"s !The Persistence of Memory" fits both perspectives quite well:



Einstein once illustrated the subjectivity of time experience in the following way:

“An hour sitting with a pretty girl on a park bench passes like a minute, but a minute sitting on a hot stove seems like an hour.” [19]

**Consequences - Time Dilation:**

- As seen by $S_1$, light sent by $S_2$ follows path shown, taking time $t$ to get from the origin of $S_2$ to the mirror and back.
- New time interval $T_1$, measured by $S_1$, is $T_1 = 2T$ where $(ct)^2 = d^2 + (vt)^2$

  Solve for $t$:

$$t = \frac{d}{c^2 - v^2}$$

$$or, T_1 = \frac{2d}{c} \frac{1}{\sqrt{1 - \frac{c^2}{v^2}}}$$

$$or, T_1 = \gamma T_{02}$$

$$where, \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Since $\gamma \geq 1$ always

⇨ $T_1 \geq T_{02}$

(Relativistic $T$ > Proper $T$ [20]

**General Theory of Relativity:**

The General Theory of Relativity is, as the name indicates, a generalization of the Special Theory of Relativity. It is certainly one of the most remarkable achievements of science to date, it was developed by Einstein with little or no experimental motivation but driven instead by philosophical questions: Why are inertial frames of reference so special? Why is it we do not feel gravity's pull when we are freely falling? Why should absolute velocities be forbidden but absolute accelerations by accepted?

Einstein at his desk in the patent office in Bern 1902

**The happiest thought of my life:**

In 1907, only two years after the publication of his Special Theory of Relativity, Einstein wrote a paper attempting to modify Newton's theory of gravitation to fit special relativity. Was this modification necessary? Most emphatically yes! The reason lies at the heart of the Special Theory of Relativity: Newton's expression for the gravitational force between two objects depends on the masses and on the distance separating the bodies, but makes no mention of time at all. In this view of the world if one mass is moved, the other perceives the change (as a decrease or increase of the gravitational force) *instantaneously*. If exactly true this would be a physical effect which travels faster than light (in fact, at infinite speed), and would be inconsistent with the Special Theory of Relativity. The only way out of this problem is by concluding that Newton's gravitational equations are not strictly correct. As in previous occasions this does not imply that they are "wrong", it only means that they are not accurate under certain circumstances: situations where large velocities (and, as we will see, large masses) are involved cannot be described accurately by these equations. In 1920 Einstein commented that a thought came into his mind when writing the above-mentioned paper he called it "the happiest thought of my life":

> *The gravitational field has only a relative existence... Because for an observer freely falling from the roof of a house – at least in his immediate surroundings – there exists no gravitational field.* [21]

**The Lorentz transformations:**

**The derivation:**

Consider a coordinate system, $S'$, moving relative to another system, $S$. Let the constant relative speed of the frames be $v$. Let the corresponding axes of $S$ and $S'$ point in the same direction, and let the origin of $S'$ move along the $x$ axis of $S$, in the positive direction. Nothing exciting happens in the $y$ and $z$ directions, so we'll ignore them. Our goal in this section is to look at two events (an event is anything that has space and time coordinates) in spacetime and relate the $\Delta x$ and $\Delta t$ of the coordinates in one frame to the $\Delta x'$ and $\Delta t'$ of the coordinates in another. We therefore want to find the constants A, B, C, and D in the relations,

$$\begin{aligned} \Delta x &= A\Delta x' + B\Delta t' \\ \Delta t &= C\Delta t' + D\Delta t' \end{aligned} \quad [22]$$

Black Holes and Time Warps: Einstein's Outrageous Legacy:

It is dangerous to ask a scientist to review a book on science that is intended for a lay audience, particularly if the subject of the book is close to the reviewer's own specialty, as in this case. So I may not be the best qualified to judge how effectively this book reaches its intended readers. Nevertheless, I can say with confidence that Kip Thorne's account of the "outrageous" consequences of the general theory of relativity is one of the best popularizations of science that I have read. It is surely the best by far of the many popular books on relativity theory. An essential part of the appeal of the book is its subject, for the general theory of relativity is arguably the very greatest triumph of the human intellect, and nothing better illustrates the profound beauty of the natural laws that govern the universe. Thorne brings a unique set of qualifications to the demanding task of explaining relativity to the lay person.

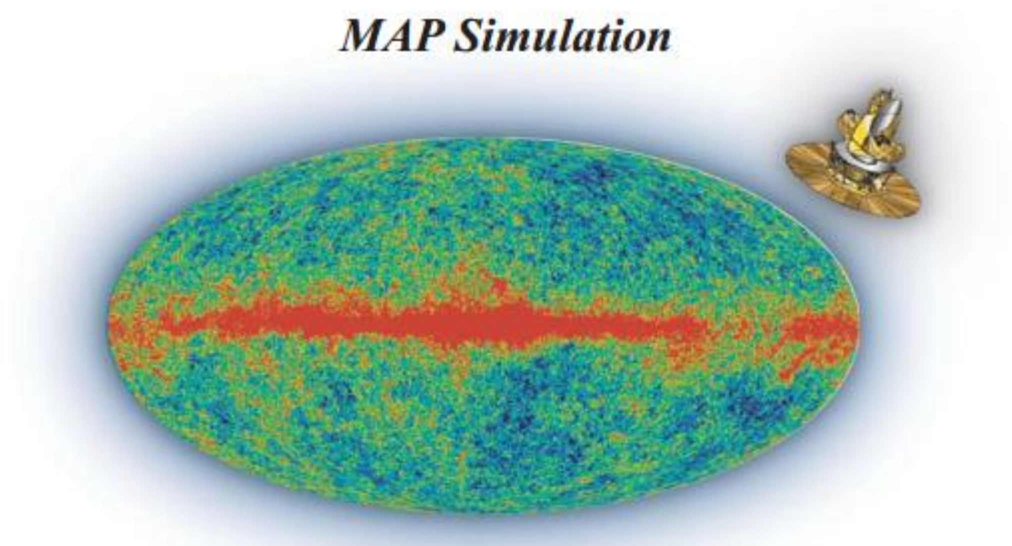
First, few active researchers can match his deep grasp of the relevant science.

Second, he is a gifted teacher whose pedagogical skills have been well honed by guiding a generation of Caltech students through the subtleties of relativity. Third, he writes prose that is lucid and absorbing.

Finally, he has an insider's view of the exciting developments, stretching back to the early 60's, that are the focus of most of the book. Rarely has a world class scientist shown such devotion in the preparation of a non-technical book; Thorne worked on the manuscript, on and off, for some 15 years. It traces the history of relativity theory from its origins in the early 20th century and documents the subsequent struggle to understand the theory and its implications. Though Thorne is not a historian, he recounts this history with meticulous attention to detail. In particular, he conducted taped interviews with 47 scientists who were directly involved in the developments that he describes. For the earlier history, he relies more heavily on secondary sources, but he has also studied many of the original research articles. (In the case of Einstein's papers, it was necessary for Thorne to read many of them in Russian, because he does not read German and they have never been translated into English.) The sources are well documented in the notes at the back of the book. [23]

**What Powered the Big Bang:**

During the last decade, sky maps of the radiation relic of the Big Bang—first by NASA's Cosmic Background Explorer (COBE) satellite and more recently by other experiments, including Antarctic balloon flights and NASA's Microwave Anisotropy Probe (MAP)—have displayed the wrinkles imprinted on the Universe in its first moments. Gravity has pulled these wrinkles into the lumpy Universe of galaxies and planets we see today.




*Simulation of the map of the cosmic microwave background that is being obtained by NASA's Microwave Anisotropy Probe (MAP).*

**Einstein's Legacy**

Einstein sought, but never achieved, an understanding of how nature works at its deepest level. We now seek the next level of Einstein's quest through a program of missions we can conceive and design today and carry out over the next decade. In the future, the "vision missions" of this roadmap will extend these ventures even closer to the edges of space and time. We will follow matter to the very brink of black holes and detect quanta or particles of time left over from the beginning of the Universe. We will use breakthrough technologies to see beyond the vision of Einstein—to the uttermost extremities of existence. [24]

**Fundamental Errors of Theory of Relativity:**

The notion of black holes voraciously gobbling up matter, twisting spacetime into contortions that trap light, stretching the unwary into long spaghetti-like strands as they fall inward to ultimately collide and merge with an infinitely dense point-mass singularity, has become a mantra of the astrophysical community. There are almost daily reports of scientists claiming that they have again found black holes again here and there. It is asserted that black holes range in size from micro to mini, to intermediate and on up through to supermassive behemoths and it is accepted as scientific fact that they have been detected at the centres of galaxies. Images of black holes interacting with surrounding matter are routinely included with reports of them. Some physicists even claim that black holes will be created in particle accelerators, such as the Large Hadron Collider, potentially able to swallow the Earth, if care is not taken in their production. Yet contrary to the assertions of the astronomers and astrophysicists of the black hole community, nobody has ever found a black hole, anywhere, let alone imaged one. The pictures adduced to convince are actually either artistic impressions (i.e. drawings) or photos of otherwise unidentified objects imaged by telescopes and merely asserted to be due to black holes, ad hoc. [25]

**Conclusion:**

This principle of relativity was accepted (in somewhat simpler form i.e. with respect to the mechanical behaviour of bodies) by Newton and his successors, even though Newton postulated that underlying it all was ‘absolute space’ which defined the state of absolute rest. He introduced the notion in order to cope with the difficulty of specifying with respect to what an accelerated object is being accelerated. To see what is being implied here, imagine space completely empty of all matter except for two masses joined by a spring. Now suppose that the arrangement is rotated, that is, they undergo acceleration. Naively, in accordance with our experience, we would expect that the masses would pull apart. But why should they? How do the masses ‘know’ that they are being rotated? There are no ‘signposts’ in an otherwise empty universe that would indicate that rotation is taking place. By proposing that there existed an absolute space, Newton was able to claim that the masses are being accelerated with respect to this absolute space, and hence that they would separate in the way expected for masses in circular motion. But this was a supposition made more for the convenience it offered in putting together his Laws of motion, than anything else. It was an assumption that could not be substantiated, as Newton was well aware – he certainly felt misgivings about the concept! Other scientists were more accepting of the idea, however, with Maxwell's theory of electromagnetism for a time seeming to provide some sort of confirmation of the concept.

Around 1907, Minkowski's scientific reputation rested largely upon his contribution to number theory.3 Yet Minkowski was also the author of an article on capillarity (1906) in the authoritative Encyklopadie der mathematischen Wissen- ¨ schaften, granting him a credential in the domain of mechanics and mathematical physics. In addition, Minkowski had lectured on capillarity, potential theory, and analytical mechanics, along with mathematical subjects such as Analysis Situs and number theory at Zurich Polytechnic, where Einstein, Marcel Grossmann and Walter Ritz counted among his students; he also lectured on mechanics an electrodynamics (among other subjects) in Gottingen, where he held the third chair in ¨ mathematics, created for him at David Hilbert's request in 1902.4 In Gottingen, Minkowski took an interest in a subject strongly a ¨ ssociated with the work of many of his new colleagues: electron theory. An early manifestation of this interest was Minkowski's co-direction of a seminar on the subject with his friend Hilbert, plus Gustav Herglotz and Emil Wiechert, which met during the summer semester of 1905.5 While Lorentz's 1904 paper (with a form of the transformations now bearing his name) was not on the syllabus, and Einstein's 1905 paper had not yet appeared, one of the students later recalled that Minkowski had hinted that he was engaged with the Lorentz transformations.

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